IN-MINEFIELD EFFECTIVENESS MEASURE FOR BREACHING VEHICLES

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I INTRODUCTION

The development of realistic models is required to assess the military worth of countermine systems in mine warfare scenarios. Explicit closed form solutions delineating countermine equipment effectiveness are being developed to become modular components of a more complex war game modelling mine warfare.

This report develops a closed solution to measure the effectiveness of armored vehicles proceeding through cleared lanes. An equation is derived to determine the expected number of mines a vehicle will encounter in a scenario. The expected number of mine encounters is used to calculate a measure to compare the value of changes in tactical methods and countermine materiel.

A discussion of the applicability of the effectiveness measure to support mine and countermine studies is also presented. A set of mine warfare situations are formulated as an example of the ease of using the expression derived in this report.

II BACKGROUND

In June 1980, USAES requested MERADCOM to perform analyses determining what marking systems could be used with mine-clearing rollers. MERADCOM tasked HEL who, in turn, subcontracted Armament Systems, Inc. and the final report, "An Investigation of Requirements for Cleared-Lane Marking Systems (CLAMS) for Hasty Breaching of Minefields with Mine-Clearing Rollers," was completed in March 1981. Section 5.0 of this report, "Assessment of the Problems Associated with Traversing and Marking a Minefield," thoroughly discusses doctrine, literature and field test data and reports on requirements of the width of a cleared lane. The requirements established in sources such as FM 90-7 "Obstacles" (which states a 4 meter wide vehicle assault lane may be used for

the nasty breach), and, the final report by the USA Armor and Engineering Board of OT II testing of the Mine-Clearing Roller (that notes the width of the lane cleared by one tank with a roller is inadequate to allow safe tracking by other tanks and personnel carriers), are not driven by , or directly related to, mobility mission requirements or effectiveness. Some procedure is necessary to aid translating mission requirements into equipment performance requirements and the converse. With the expression developed here, postulated systems performance functions can generate values of in-minefield effectiveness as the measure of the expected number of mines a vehicle will encounter.

III OBJECTIVE AND SCOPE

The objective of this report is to derive an equation to calculate expected mine encounters of vehicles crossing a minefield, and describe methods in computing and applications of results of the equation to determine in-minefield effectiveness (IME) measures of various systems.

The mathematical scope of the derivation extends to an integral calculus statement:

$$\int_{AREA} (\text{density function})\, d(AREA) = \text{units} \tag{1}$$

For the application here, this translates to: the integral of the density function in mines per square meter over the area swept out by a vehicle passing through a minefield is equal to the number of mines the vehicle will encounter. This would be exactly true if mines were a continuous phenomenon. But since they are point located, or at best disjoint, this equation is an approximation to the expected number of mine encounters. This method does not calculate where a vehicle will encounter a mine, only the expected number of encounters that are found in the area used in the calculation. This expected value is the identical concept to the average, or mean value.

Actual mine location will vary under a host of conditions (mine laying procedure, minefield layout, etc.), so there is a possiblity that, though the expected value of encounters in an intended path is positive, actually transversing the minefield will result in no mine encounters.

Under rather standard assumptions of randomness, the occurrance of mine encounters can be treated as a Poisson process. Arguements to independent and identical distributions are not very serious because, firstly, the calculation derived is an approximation, and secondly, the performance measure relates to the probability of no occurances, so the memoryless criteria of such a process is robust. According to a Poisson distribution, the probability of n occurances, Pr(n), given that the expected number of occurances is λ, is given by equation 2.

$$Pr(n) = \frac{\lambda^n e^{-\lambda}}{n!}, \tag{2}$$

The probability of encountering no mines (n=0) given the expected number of encounters, λ, to be E(N) is

$$Pr(0 \text{ mines}) = e^{-E(N)} \tag{3}$$

This probability is the in-minefield effectiveness measure.

Included in the IME equation derived within is a parameterized function that describes the vehicle path and a probability distribution function of random play about the path. The resulting product of functions provides a flexibility in the quantifiable description of countermining situations. Moreover, the results are immediately and inexpensivly obtained compared to simulations and war games of similar scope.

IV DERIVATION

Let $\delta(x,y)$ be the minefield density function over some Cartesian coordinate system; typical units for such a function are mines per meter squared (M/m^2). Take, for example, a situation at FIG 1. In this example, a mechanically emplaced minefield of 3 rows of pressure AT mines with an inter-mine spacing of four meters would require 300 mines. Since the area of this minefield is 20,000 square meters, the overall density of the minefield is $0.015M/m^2$. An alternate representation of this minefield could partition the mine rows into separate minefields. Using the variables defined in the figure, the expected number of mines, E(N), a vehicle would encounter is $2 \cdot (\text{ote}-\text{ite}) \cdot d \cdot \delta$. The difference, in meters, from the outer track edge to the inner track edge (ote-ite) is one track-width. For this example, $E(N)=2\cdot(\text{ote}-\text{ite})\cdot 50\cdot 0.015=1.5\cdot(\text{ote}-\text{ite})$ or 1.5 times a track-width of the vehicle (in meters). This calculation is simply the area swept out by the vehicles tracks times the constant minefield density. In integral form, however,

$$E(N) = \int_0^d \left(\int_{w/2-\text{ote}}^{w/2-\text{ite}} \delta(x,y)\, dx + \int_{w/2+\text{ite}}^{w/2+\text{ote}} \delta(x,y)\, dx \right) dy \qquad (4)$$

Since $\delta(x,y) = 0.015\ M/m^2$ for $0 \leq x \leq w$, $0 \leq y \leq d$, we have,

$$E(N) = \int_0^d 0.015 \left(\int_{w/2-\text{ote}}^{w/2-\text{ite}} dx + \int_{w/2+\text{ite}}^{w/2+\text{ote}} dx \right) dy$$

$$= \int_0^d ((0.015\cdot 2)(\text{ote}-\text{ite}))dy$$

$$= 0.030(\text{ote}-\text{ite})d$$

$$= (1.5)(\text{ote}-\text{ite}) \qquad (5)$$

Nomenclature for the IME Equation

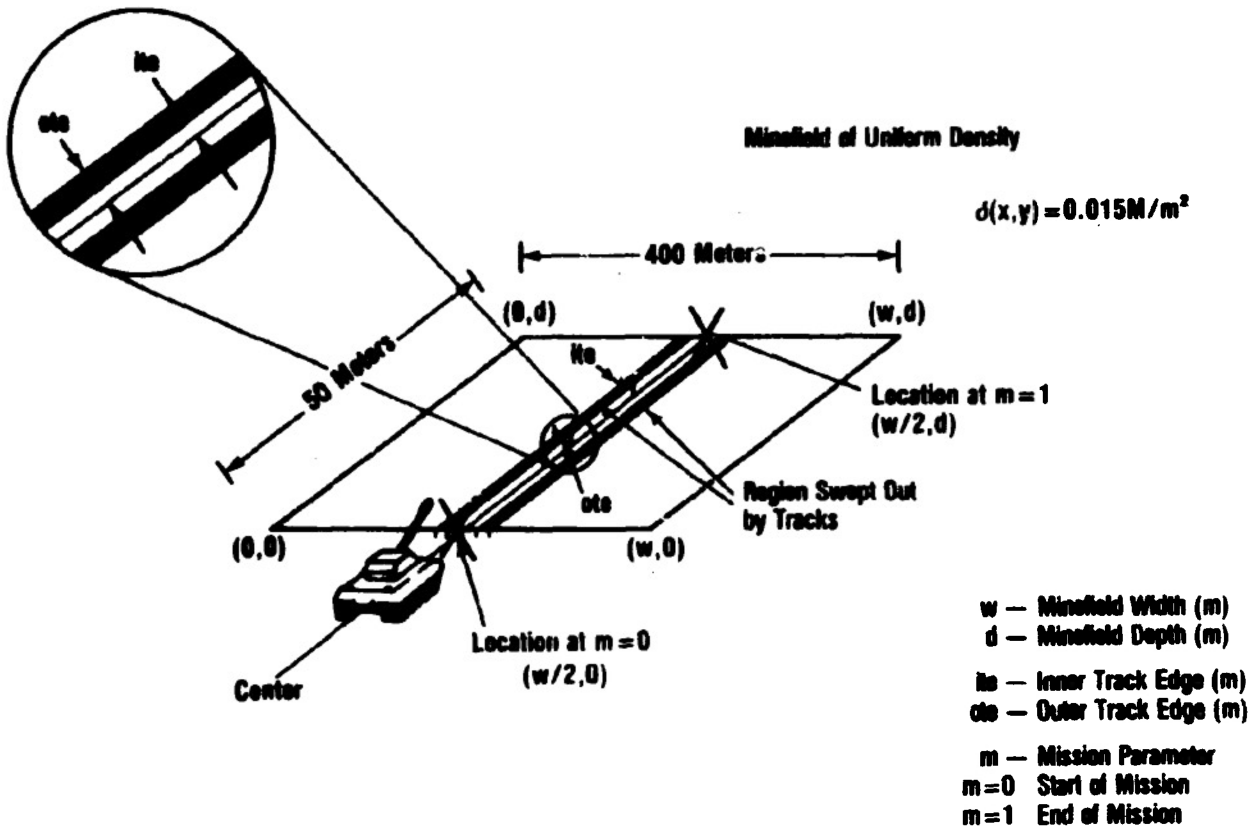

Figure 1. STRAIGHT LINE PATH THROUGH A MINEFIELD

This is the identical result obtained eariler.

Consider now that the vehicle goes through the minefield on something other than a straight line path. Define $P(m) = (X(m),Y(m))$ as the parametrical representation of such a path, where m ranging from 0 to 1 relates to the amount of the mission complete (i.e., m=0 is the start of the mission, m=1 the end). The areas swept out by tracks of a vehicle are no longer simple rectangles, as shown at FIG 2. Incorporating this parametrical path representation, equation (3) becomes

$$E(N) = \int_0^1 \left(\int_{olx}^{ilx} \delta(x,y)(dY/dm)dx + \int_{irx}^{orx} \delta(x,y)(dY/dm)dx \right) dm$$

where olx = outer left-track x = $X(m) - ote/\sqrt{1+s^2(m)}$

ilx = inner left-track x = $X(m) - ite/\sqrt{1+s^2(m)}$

irx = inner right-track x = $X(m) + ite/\sqrt{1+s^2(m)}$

orx = outer right-track x = $X(m) + ote/\sqrt{1+s^2(m)}$

$y = Y(m) + s^2(m)(X(m)-x)$

$$s(m) = \frac{-dX/dm}{dY/dm} \tag{6}$$

Analytically, this integral represents the summation of partitioned rectangles that make up the area traced by the vehicle tracks, as shown in FIG 3.

Thus far, vehicles are restricted to following the prespecified paths perfectly. A probability distribution function of play about the path is inserted to account for effects of vehicles not able to follow precise paths. This play function, $\Omega(z,m)$, is dependent upon distance from the path, z, and the mission parameter measure, m. The final form for the expected number of mine encounters is

$$E(N) = \int_0^1 \int_{-\infty}^{+\infty} \Omega(z,m) \left(\int_{olx}^{ilx} \delta(x,y)(dY/dm)dx + \int_{irx}^{orx} \delta(x,y)(dY/dm)dx \right) dz\, dm$$

Projection of Non-Perpendicular Orientations onto the X-Axis

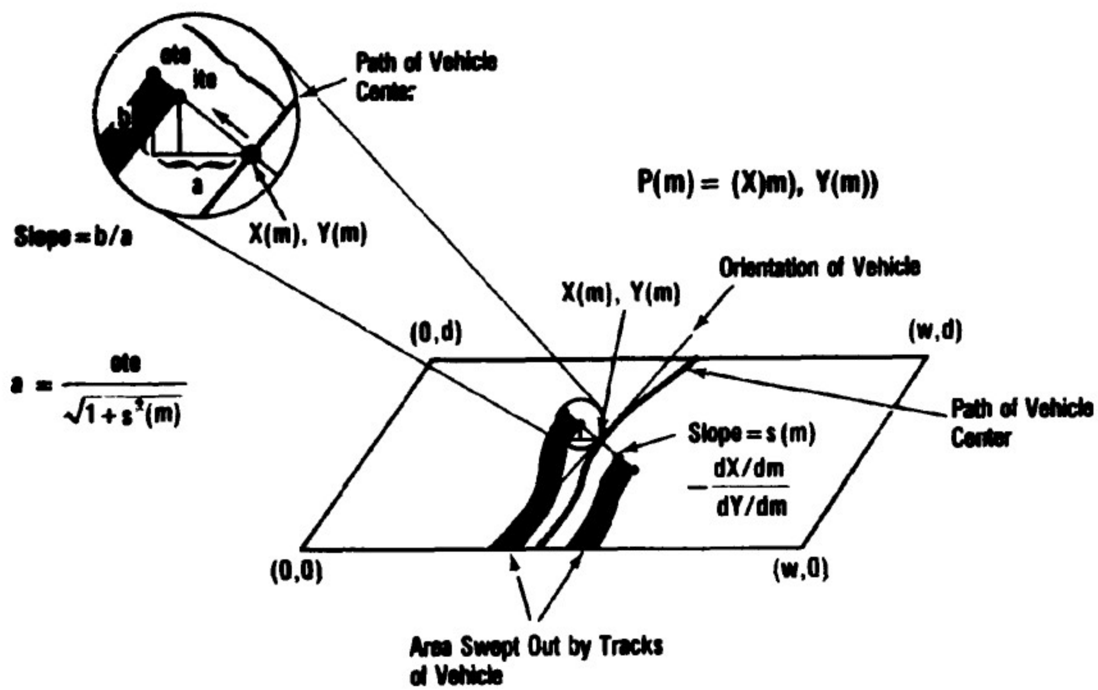

Figure 2. NON-LINEAR PATH THROUGH A MINEFIELD

Partitioning of the Area Integrated by the IME Equation

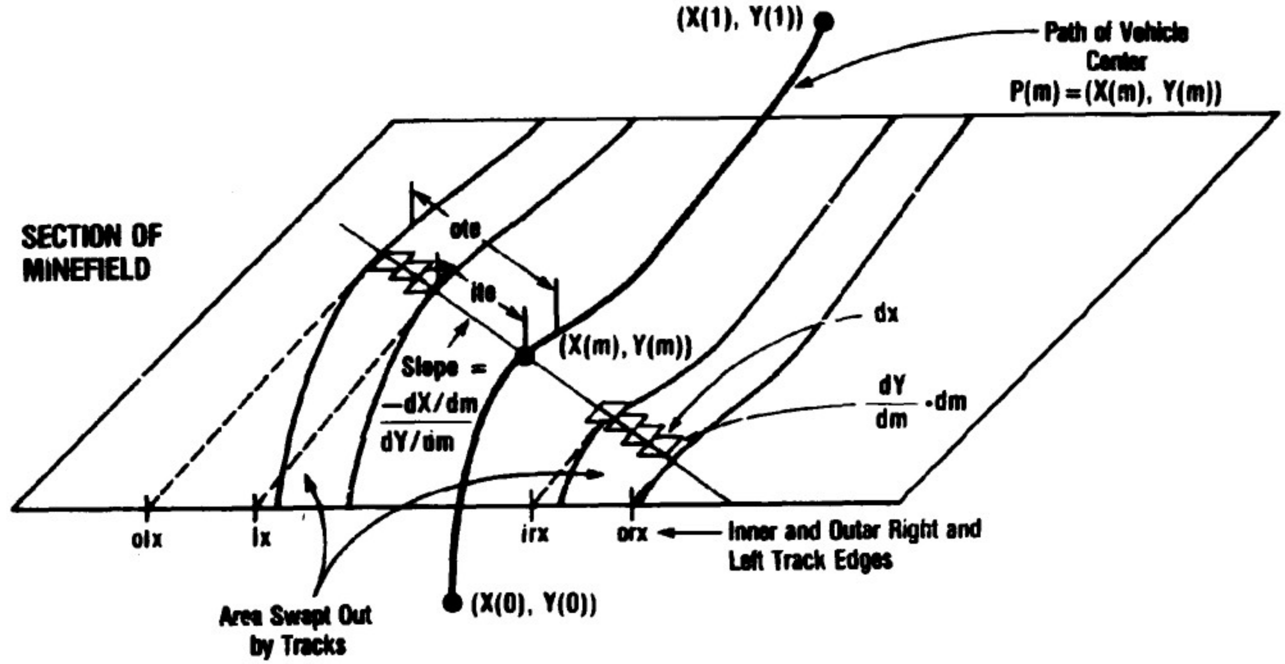

Figure 3. GRAPH OF PARAMETERIZED PATH THROUGH A MINEFIELD

where $olx = X(m) - (ote-z)/\sqrt{1+s^2(m)}$

$ilx = X(m) - (ite-z)/\sqrt{1+s^2(m)}$

$irx = X(m) + (ite+z)/\sqrt{1+s^2(m)}$

$orx = X(m) + (ote+z)/\sqrt{1+s^2(m)}$

y, s(m) as defined in equation (6). (7)

Once E(N) is calculated, the probability of the vehicle traversing the path P(m) with play function $\Omega(z,m)$ through a minefield density $\delta(x,y)$ without encountering a mine is given by equation (3):

$$Pr(0 \text{ mines}) = e^{-E(N)}$$

The Pr(0 mines) is the in-minefield effectiveness (IME) measure for breaching vehicles. Being a probability, the IME measure will always fall between 0 and 1, the latter designating a certainty of no mine encounters. The closer the IME is to one, the better the chances a vehicle will successfully cross the minefield.

V APPLICATION

This section presents sample applications of the IME measure equation. The intent of this section is to demonstrate the flexibility of the model; it is not an exhaustive list of the capability of the procedure. The situations to be studied will dictate the forms of three functions: minefield density, vehicle path, and path play.

Let us choose as a problem measuring the ability of follow-on vehicles to breach a minefield first cleared by a single lead tank equipped with a mine-clearing roller and cleared lane marking system.

A minefield density function to represent this situation must be formulated. Consider the mechanically emplaced minefield of 300 mines in a 400 meter by 50 meter rectangle discussed earlier. Before any neutralization, the density could be taken as a constant $0.015M/m^2$. As the lead tank equipped with a roller passes through the minefield and detonates mines, the density of the minefield is lowered. Assuming perfect capabilities, and a straight line breach

perpendicularly through the center of the minefield, the density of the minefield drops to zero within the two rectangles traced out by the signature of the roller banks. A representative minefield density function before and after nuetralization is shown at FIG 4. The after-neutralization minefield density function is used to determine the expected number of mines encountered by follow-on vehicles. The algebraic expression of this density function is

$$\delta(x,y) = \begin{cases} 0.0 & 0.9 \leq |x-200| < 2.0 \\ 0.015 & \text{otherwise, } 0 \leq x \leq 400,\ 0 \leq y \leq 50 \end{cases} \tag{8}$$

Physically, equation (8) models a lead tank that crossed the minefield at mid-front (x=200 of the 400 m minefield), with 2 mine-clearing roller banks 1.1 m wide separated by 1.8 meters.

The second of the three IME functions, the vehicle path, models the attempted path of follow-on vehicles making full advantage of neutralized zones. In this instance, the intended path for such vehicles is to retrace the straight line path of the lead tank guided by some marking system. The parameterized form of this path is

$$P(m) = (X(m), Y(m)) : \begin{array}{l} X(m) = 200 \\ Y(m) = 50 \cdot m \end{array} \tag{9}$$

At the start of the mission, the vehicle is at P(0) which is (200, 0) on the Cartesian system employed. By the end of the mission (m=1), the vehicle has travelled in a straight line to (200, 50); this is the same path as the roller equipped lead tank.

However, due to many conditions, follow-on vehicles cannot exactly duplicate the lead tank path. A family of play functions is postulated and implemented to model the ability of these follow-on vehicles to stay on the intended path. The play function can be interpreted as the capability of the driver of a follow-on vehicle to stay on the intended path based on his skills, training, driving aid devices, and/or marking systems. A perfect path follow-on vehicle could be thought of as one whose play never strays off the intended trace (i.e. the center

Mine-Clearing Roller Effects on a Uniform Density Minefield

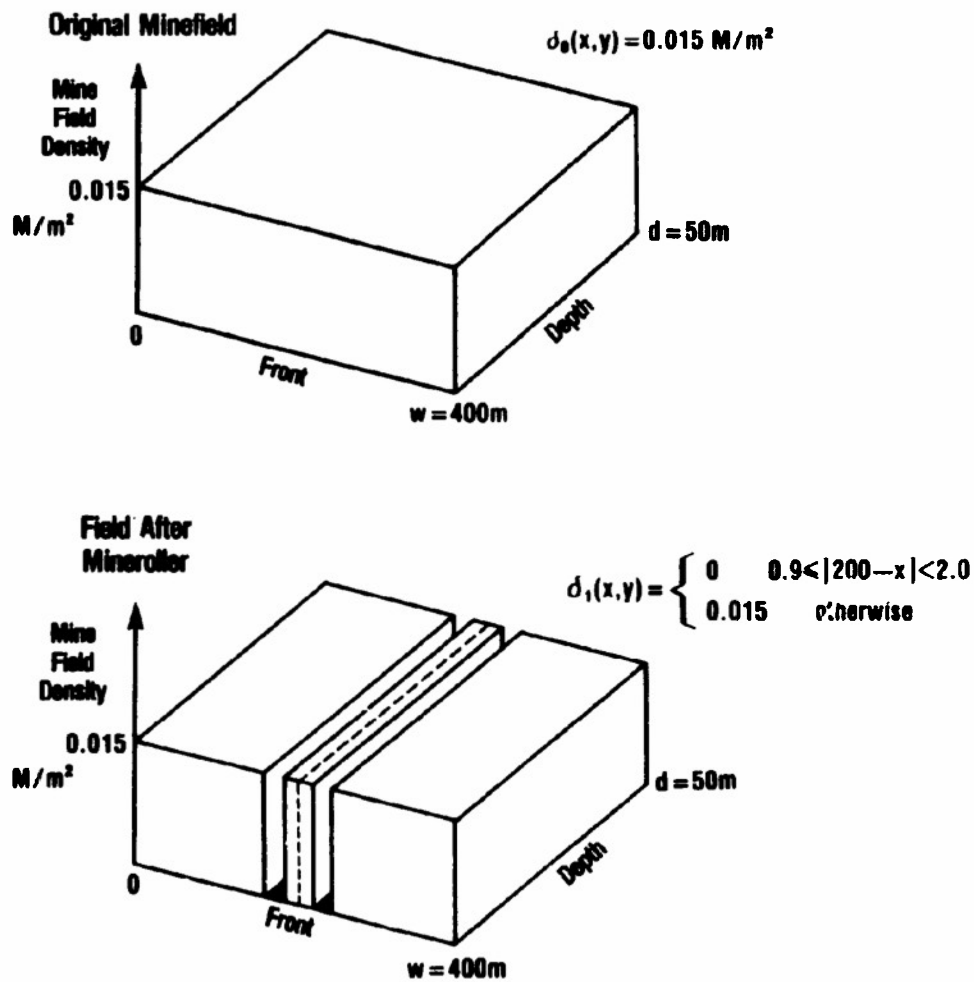

Figure 4. MINEFIELD DENSITY BEFORE AND AFTER NEUTRALIZATION

o. the follow-on vehicle exactly retraces the center of the path of the lead vehicle). As conditions drop from less than perfect, follow-on vehicles have higher probabilities to stray away from the intended path. The sample play functions used in this application are at FIG 5.

The discontinuous nature of $\delta(x,y)$ and several of the $\Omega(z,m)$ functions lead to cumbersome arithmetic calculations. To ease this problem, a computer program[1] was written to readily analyze the expressions. Table I is a summary of sample applications of the IME methodology. Column four of this table shows the IME measures for the postulated systems. The effective path width listed in Column five is the sum of the range of play allowed and the width of the follow-on vehicle.

The IME measures change significantly over the set of play functions. For test run 1, the IME is 1.00, meaning 100% chance of crossing the minefield without mine encounter. This is a reasonable result, for this trial is with no play; the follow-on vehicle path exactly matches the lead tank path, and the tracks of the follow-on vehicles will always fall between the bounds of the safe zones cleared by the rollers. Allowing the vehicle to sway $\pm$ 0.5 m from the perfect lane (trial 2) drops the chance of encountering no mines 5 percentage points. Normally distributed play functions perform better than triangularly distributed ones of equal range (trial 3 vs 5 and 4 vs 6) because the normal distributions have a greater central tendency (they hug the line better) than the triangular distributions.

The IME measure indicates that a reduction in play of 1 meter betters the probability of no mine encounters by 0.13 (trial 6 compared with trial 5). The chance of encountering no mines jumps from 72% to 85% when the follow-on vehicle

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[1]A listing of this program, written in SIMSCRIPT II.5, is in the Appendix.

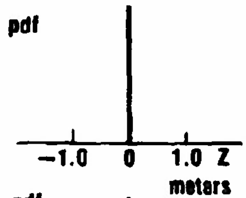
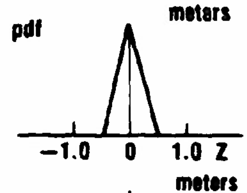
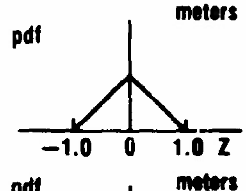
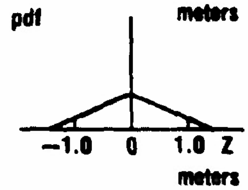
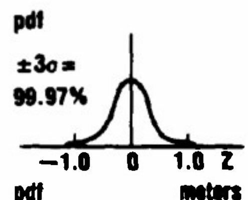
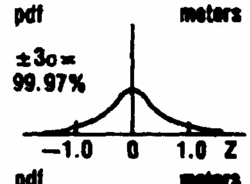
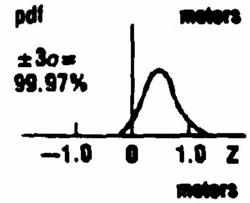
Test	Description	Range (m)	Ω (z,m)	Comment
1	No Play.	0.0		Perfect Tracing of Path.
2	Triangular Distribution	1.0		
3	Triangular Distribution	2.0		
4	Triangular Distribution	3.0		
5	Normal Distribution	2.0		$\mu = 0.0$ $\sigma = 1/3$
6	Normal Distribution	3.0		$\mu = 0.0$ $\sigma = 1/2$
7	Normal Distribution	2.0		$\mu = 0.5$ $\sigma = 1/3$ (Right Bias)

Figure 5. SAMPLE PLAY FUNCTIONS USED IN THE IME APPLICATIONS

Assumptions:

Minefield: 400 × 50m
3 Rows of AT Mines 4.0m Apart

Follow-on Vehicle Track Signature:

Track	Belly	Track	
.7m	2.2m	.7m	3.6 Total Meters

Inner Track Edge = ite = 1.1m
Outer Track Edge = ote = 1.8m

Neutralization: Straight Path Through Minefield Center with Roller

2 Cleared Zones 1.1m Each, 1.8 Meters Apart

Cleared	Un-cleared	Cleared
1.1m	1.8m	1.1m

$$IME = e^{-E(N)}$$

$$E(N) = \int_0^1 \int_{-\infty}^{\infty} \Omega(z,m) \left[{}_{etx}\int^{itx} \delta(x,y) \frac{dY}{dm}\, dx + {}_{irx}\int^{orx} \delta(x,y) \frac{dY}{dm}\, dx \right] dz\, dm$$

$$\delta(x,y) = \begin{cases} 0 & 0.9 < |x-200| < 2.0 \\ 0.015 & \text{otherwise} \end{cases}$$

Results:

Test Run	$\Omega(z,m)$ Play Function About Path	E(N) = Expected Number of Mine Encounters	IME = Prob. of Encountering Zero Mines	Effective Path Width
1	None	0.000	1.00	3.6m
2	Triangular, Range = 1m	0.054	0.95	4.6m
3	Triangular, Range = 2m	0.256	0.77	5.6m
4	Triangular, Range = 3m	0.440	0.64	6.6m
5	Normal, Range = 2m	0.165	0.85	5.6m
6	Normal, Range = 3m	0.32[illegible]	0.72	6.6m
7	Normal, Right Bias, Range = 2m	0.473	0.62	5.6m

Table I. SUMMARY OF SAMPLE APPLICATION OF THE IN-MINEFIELD EFFECTIVENESS MEASURE

restricts its deviation about the path a half meter on each side. This translates to a potential benefit due to increased survivability. This benefit can be realized through increased driver skill, improved training, and/or cleared-lane marking system, any approaches to result in less play of follow-on about a clear path.

The following section describes a study done to evaluate marking systems and how IME could have been employed to achieve meaningful results.

VI DISCUSSION

The Concept Evaluation Program of CLAMS (3 December 1981, TRADOC ACN 52725) compared the operational performance of chemiluminescent candles to highway safety flares in marking a breach through a minefield. Trial runs were scored as successful if a vehicle stayed within predetermined path widths 88% of the time during a breach. Measurements were taken as the vehicle passed each marker. Results from this test were non-conclusive. Only 7 of 203 attempts by M60 tanks to negotiate a 4 meter path were successful. The binary nature of the outcome of a trial (labeled success or failure) contributed greatly to the insensitivity of the results of the field experiments. Moreover, the outcome labels had little to do with mission success or failures of vehicles breaching hypothetical minefields as those simulated by the tests. Failure to maintain a four meter path in the test did not directly equate to failure to breach the simulated minefield, and the same is true for success. There was no reference to a real military worth.

The IME equation provides the means to combine minefield density, vehicle track signature and path into a quantitative assessment of military worth. The example results show the gains in terms of higher survivability by achieving narrower vehicle path tracings. Field experiments taken to measure vehicle path functions can be translated into quantitative measures attributable to the military worth of the marking systems through the IME.

V CONCLUSIONS

The IME measure is an easily calculated, yet sensitive indicator of the performance of mine and countermine systems. Elements of mine/countermine systems can be modelled by the various data and function inputs to the IME equation, as listed in Table II. Complex functions can be evaluated with a computer program specifically designed to solve IME equations. The IME measure is a useful index because it translates system performance characteristics of alternative mine/countermine systems into survivability figures. The IME process can quantify benefits of new developments, whether organizational, operational, or materiel in nature. IME measures can also be used as input to higher level, larger scope war games where previous data were randomly generated or estimated.

Examples of other uses of IME are:

a. Mixed mine type minefield effectivness. The different mine type densities and corresponding track or vehicle signatures can initially be separated out and later combined for an aggregate effectiveness measure.

b. Smart mine design parameters. The parameterized path function can be time normalized and probability of mine/vehicle encounter based on duration of exposure as well as area.

c. Countermine systems mix analyses. Single systems and combination can be studied.

d. Wide area countermine systems analyses. Hypothetical countermine system performances can be compared as to how well they neutralize threat minefields for follow on vehicles.

MINE/COUNTERMINE ELEMENT	IME EQUATION COMPONENTS THAT MODEL ELEMENT	
MINE DETECTION	δ (x,y)	Minefield density
	Ω (z,m)	Play
MINE NEUTRALIZATION	δ (x,y)	Minefield density
	P(m)	Path
MARKING SYSTEMS	P(m)	Path
	Ω (z,m)	Play
TERRAIN	P(m)	Path
	δ (z,m)	Play
FUZING/TANK SIGNATURE INTERACTIONS	ite	inner track edge dimension
	ote	outer track edge dimension
MINE LAYING PATTERN	δ (x,y)	Minefield density
TRAINING AND DOCTRINE	δ (x,y)	Minefield density
	P(m)	Path
	Ω (z,m)	Play

TABLE II. IME EQUATION COMPONENTS MODELLING MINE/COUNTERMINE ELEMENTS

ABBREVIATIONS

AT	Antitank
CLAMS	Cleared-Lane Marking System
FAE	Fuel-Air Explosive
HEL	Human Engineering Laboratory
IME	In-Minefield Effectiveness
OT	Operational Testing
USAES	U.S. Army Engineer School
m	meters
M/m^2	mines per meter squared

SYMBOLS

d	depth of minefield (meters)
w	width of minefield (meters)
m	mission parameter $0 \leq m \leq 1$
x	position within minefield along the width (meters)
y	position within minefield along the depth (meters)
z	deviation from prescribed path (meters)
ite	inner track edge; the distance from the center of a vehicle to the inner track edge (meters)
ote	outer track edge; the distance from the center of a vehicle to the outer track edge (meters)
ilx	inner left track edge integrand
irx	inner right track edge integrand
olx	outer left track edge integrand
orx	outer right track edge integrand
P(m)	parameterized path function
X(m)	X component of path
Y(m)	Y component of path
dX/dm	first derivative of X(m)
dY/dm	first derivative of Y(m)
s(m)	slope of vehicle orientation at m
E(N)	the expected value of the number of mine encounters
Pr(n)	the probability of n occurances
$\delta(x,y)$	delta, the minefield density function
λ	lambda, the mean
μ	mu, the mean of a normal distribution
σ	sigma, the standard deviation of a normal distribution
$\Omega(z,m)$	omega, the play function
∞	infinity

APPENDIX

COMPUTER PROGRAM LISTING FOR THE [illegible] EQUATION

INDEX	A1
LISTING	A2 - A4
TEST RUN 1 PLAY FUNCTION AND INPUT FILE	A5
TEST RUN 1 OUTPUT	A6
TEST RUN 2 PLAY FUNCTION AND INPUT FILE	A7
TEST RUN 2 OUTPUT	A8
TEST RUN 3 PLAY FUNCTION AND INPUT FILE	A9
TEST RUN 3 OUTPUT	A10
TEST RUN 4 PLAY FUNCTION AND INPUT FILE	A11
TEST RUN 4 OUTPUT	A12
TEST RUN 5 PLAY FUNCTION AND INPUT FILE	A13
TEST RUN 5 OUTPUT	A14
TEST RUN 6 PLAY FUNCTION AND INPUT FILE	A15
TEST RUN 6 OUTPUT	A16
TEST RUN 7 PLAY FUNCTION AND INPUT FILE	A17
TEST RUN 7 OUTPUT	A18

```
PREAMBLE
  NORMALLY, MODE IS REAL
  DEFINE DELTA, PLAY, SLOPE AS REAL FUNCTIONS WITH 2 ARGUMENTS
  DEFINE DY.DM, X.POS, Y.POS AS REAL FUNCTIONS WITH 1 ARGUMENT

  END AAPREAMBLE
```



```

.MAIN.

  LET SUM=0.0


  READ M, Z, XX, LB, UB, ITE, OTE


  LET DM=1/M
  LET DZ=(UB-LB)/Z
  LET DXX=1/XX


  FOR M=DM/2 TO 1.0 BY DM, DO
      LET X=X.POS(M)
      LET Y=Y.POS(M)
      LET S=SLOPE(X, Y)
      LET DY=DY.DM(M)
      FOR Z=LB+DZ/2 TO UB BY DZ, DO
          LET WEIGHT=PLAY(Z, M)
          LET K=SQRT.F(1+S**2)
          LET OLX=X-(OTE-Z)/K
          LET ILX=X-(ITE-Z)/K
          FOR XX=OLX+DXX/2 TO ILX BY DXX, DO
              LET YY=Y+S*(XX-X)
              ADD DM*DZ*DXX*DY*WEIGHT*DELTA(XX, YY) TO SUM
              LOOP '' ON XX      (LEFT TRACK)

```

```
                LET IRX=X+(ITE+Z)/K
                LET ORX=X+(OTE+Z)/K
                FOR XX=IRX+DXX/2 TO ORX BY DXX, DO
                   LET YY=Y+S*(XX-X)
                   ADD DM*DZ*DXX*DY*WEIGHT*DELTA(XX, YY) TO SUM
                   LOOP '' ON XX      (RIGHT TRACK)

                LOOP ''ON Z          (PLAY)

             LOOP ''ON M            (MISSION)

         PRINT 6 LINES WITH LB, UB, ITE, OTE, SUM THUS
LOWER, UPPER BOUNDS ON VEHICLE PLAY = ***.**, ***.** METERS
       CENTER TO INSIDE TRACK EDGE = **.** METERS
       CENTER TO OUTSIDE TRACK EDGE= **.** METERS

    EXPECTED NUMBER OF MINES ENCOUNTERED = ***.***

         LET PROB=EXP.F(-SUM)
         PRINT 1 LINE WITH PROB THUS
    PROB. OF ENCOUNTERING NO MINES   IS  *.***
         FOR I= 1.0 TO 20.0 BY 1.0, DO
            LET PROB=PROB*SUM/I
            PRINT 1 LINE WITH I, PROB THUS

    PROB. OF ENCOUNTERING ** MINE(S) IS  *.***
            LOOP ''ON I.

         END ''MAIN

COC  660L   CACI SIMSCRIPT II.5 VERSION /4.5-00/  NOS-BE  1          12/22/81  14.16.05.     PA

       FUNCTION DELTA(A, B)

         IF 0.9 LE ABS.F(A-200.0) LE 2.0
            RETURN WITH 0.0
         ELSE
            RETURN WITH 0.015
         END ''DELTA FUNCTION      (OF MINE DENSITY)
```

```
CDC  6600   CACI SIMSCRIPT II.5 VERSION /4.5-80/  NOS-BE  1            12/22/81  14.16.05.    PAG

      FUNCTION X.POS(A)

        RETURN WITH 200.0
        END ''X.POS FUNCTION
```

```
CDC  6600   CACI SIMSCRIPT II.5 VERSION /4.5-80/  NOS-BE  1            12/22/81  14.16.05.    PAG

      FUNCTION Y.POS(A)

        RETURN WITH 50.0*A
        END ''Y.POS FUNCTION
```



```
CDC  6600   CACI SIMSCRIPT II.5 VERSION /4.5-80/  NOS-BE  1            12/22/81  14.16.05.    PA(

      FUNCTION DY.DH(A)

        RETURN WITH 50.0
        END ''DY.DH FUNCTION
```

```
CDC  6600   CACI SIMSCRIPT II.5 VERSION /4.5-80/  NOS-BE  1            12/22/81  14.16.05.    PA

      FUNCTION SLOPE(A, B)

        RETURN WITH 9.0
        END ''SLOPE FUNCTION
```

A11

```
FUNCTION PLAY(A, B)

  IF ABS.F(A) LE 0.025
     RETURN WITH 1.0
  ELSE
     RETURN WITH 0.0
  END ''PLAY FUNCTION
```

INPUT FILE

```
40  40  40
-1.  1.
 1.1
 1.8
```

```
LOWER, UPPER BOUNDS ON VEHICLE PLAY =  -1.00,   1.00 METERS
          CENTER TO INSIDE TRACK EDGE =  1.10 METERS
          CENTER TO OUTSIDE TRACK EDGE=  1.80 METERS

     EXPECTED NUMBER OF MINES ENCOUNTERED =   0.

     PROB. OF ENCOUNTERING NO MINES    IS  1.000
     PROB. OF ENCOUNTERING  1 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING  2 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING  3 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING  4 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING  5 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING  6 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING  7 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING  8 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING  9 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING 10 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING 11 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING 12 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING 13 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING 14 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING 15 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING 16 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING 17 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING 18 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING 19 MINE(S)  IS  0.
     PROB. OF ENCOUNTERING 20 MINE(S)  IS  0.
```

```
      FUNCTION PLAY(A, B)

        IF A LE 0.0
           RETURN WITH 2 + 4*A
        ELSE
           RETURN WITH 2 - 4*A
        END ''PLAY FUNCTION
```

INPUT FILE

```
40  40  40
-.5 .5
1.1
1.8
```


A/

```
LOWER, UPPER BOUNDS ON VEHICLE PLAY =   -.50,    .50 METERS
          CENTER TO INSIDE TRACK EDGE =  1.10 METERS
          CENTER TO OUTSIDE TRACK EDGE=  1.80 METERS

      EXPECTED NUMBER OF MINES ENCOUNTERED =    .054

      PROB. OF ENCOUNTERING NO MINES    IS    .947
      PROB. OF ENCOUNTERING  1 MINE(S)  IS    .051
      PROB. OF ENCOUNTERING  2 MINE(S)  IS    .001
      PROB. OF ENCOUNTERING  3 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING  4 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING  5 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING  6 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING  7 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING  8 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING  9 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING 10 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING 11 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING 12 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING 13 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING 14 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING 15 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING 16 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING 17 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING 18 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING 19 MINE(S)  IS    .000
      PROB. OF ENCOUNTERING 20 MINE(S)  IS    .000
```

```
CDC 6600   CACI SIMSCRIPT II.5 VERSION /4.5-08/  NOS-BE  1          12/22/81  13.59.18.     PAG

FUNCTION PLAY(A, B)

  IF A LE 0.0
     RETURN WITH 1.0+A
  ELSE
     RETURN WITH 1.0-A
  END ''PLAY FUNCTION
```

INPUT FILE

```
40  40  40
-1.  1.
 1.1
 1.8
```

```
LOWER, UPPER BOUNDS ON VEHICLE PLAY =  -1.00,   1.00 METERS
      CENTER TO INSIDE TRACK EDGE =  1.10 METERS
      CENTER TO OUTSIDE TRACK EDGE=  1.00 METERS

   EXPECTED NUMBER OF MINES ENCOUNTERED =    .256

   PROB. OF ENCOUNTERING NO MINES     IS   .774
   PROB. OF ENCOUNTERING  1 MINE(S) IS   .198
   PROB. OF ENCOUNTERING  2 MINE(S) IS   .025
   PROB. OF ENCOUNTERING  3 MINE(S) IS   .002
   PROB. OF ENCOUNTERING  4 MINE(S) IS   .000
   PROB. OF ENCOUNTERING  5 MINE(S) IS   .000
   PROB. OF ENCOUNTERING  6 MINE(S) IS   .000
   PROB. OF ENCOUNTERING  7 MINE(S) IS   .000
   PROB. OF ENCOUNTERING  8 MINE(S) IS   .000
   PROB. OF ENCOUNTERING  9 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 10 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 11 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 12 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 13 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 14 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 15 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 16 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 17 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 18 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 19 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 20 MINE(S) IS   .000
```

```
CDC 6600   CACI SIMSCRIPT II.5 VERSION /4.5-80/  NOS-BE 1          12/22/81  14.06.25.     PAC

     FUNCTION PLAY(A, B)

       IF A LE 0.0
          RETURN WITH 2/3 + 4*A/9
       ELSE
          RETURN WITH 2/3 - 4*A/9
       END ''PLAY FUNCTION
```

INPUT FILE

```
40   40   40
-1.5 1.5
1.1
1.8
```

```
LOWER, UPPER BOUNDS ON VEHICLE PLAY =  -1.50,   1.50 METERS
       CENTER TO INSIDE TRACK EDGE =  1.10 METERS
       CENTER TO OUTSIDE TRACK EDGE=  1.80 METERS

    EXPECTED NUMBER OF MINES ENCOUNTERED =     .440

    PROB. OF ENCOUNTERING NO MINES    IS    .644
    PROB. OF ENCOUNTERING  1 MINE(S)  IS    .283
    PROB. OF ENCOUNTERING  2 MINE(S)  IS    .062
    PROB. OF ENCOUNTERING  3 MINE(S)  IS    .009
    PROB. OF ENCOUNTERING  4 MINE(S)  IS    .001
    PROB. OF ENCOUNTERING  5 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING  6 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING  7 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING  8 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING  9 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 10 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 11 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 12 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 13 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 14 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 15 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 16 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 17 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 18 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 19 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 20 MINE(S)  IS    .000
```

```
CDC 6600   CACI SIMSCRIPT II.5 VERSION /4.5-08/  NOS-BE  1                12/24/81  08.47.37.     PA

        FUNCTION PLAY(A, B)

          RETURN WITH 2/SQRT.F(PI.C*2)*EXP.F(-1/2*A**2*4)
          END ''PLAY FUNCTION
```

INPUT FILE

```
40  40  40
-1.  1
 1.1
 1.8
```

```
LOWER, UPPER BOUNDS ON VEHICLE PLAY =  -1.50,   1.50 METERS
      CENTER TO INSIDE TRACK EDGE =  1.10 METERS
      CENTER TO OUTSIDE TRACK EDGE=  1.80 METERS

   EXPECTED NUMBER OF MINES ENCOUNTERED =    .321

   PROB. OF ENCOUNTERING NO MINES    IS   .725
   PROB. OF ENCOUNTERING  1 MINE(S) IS   .233
   PROB. OF ENCOUNTERING  2 MINE(S) IS   .037
   PROB. OF ENCOUNTERING  3 MINE(S) IS   .004
   PROB. OF ENCOUNTERING  4 MINE(S) IS   .000
   PROB. OF ENCOUNTERING  5 MINE(S) IS   .000
   PROB. OF ENCOUNTERING  6 MINE(S) IS   .000
   PROB. OF ENCOUNTERING  7 MINE(S) IS   .000
   PROB. OF ENCOUNTERING  8 MINE(S) IS   .000
   PROB. OF ENCOUNTERING  9 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 10 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 11 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 12 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 13 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 14 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 15 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 16 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 17 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 18 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 19 MINE(S) IS   .000
   PROB. OF ENCOUNTERING 20 MINE(S) IS   .000
```

```
FUNCTION PLAY(A, B)

  RETURN WITH 3/SQRT.F(PI.C*2)*EXP.F(-1/2*(A)**2*9)
  END ''PLAY FUNCTION
```

INPUT FILE

```
40   40   40
-1.5 1.5
1.1
1.8
```

```
LOWER, UPPER BOUNDS ON VEHICLE PLAY =  -1.00,   1.00 METERS
       CENTER TO INSIDE TRACK EDGE =  1.10 METERS
       CENTER TO OUTSIDE TRACK EDGE=  1.00 METERS

    EXPECTED NUMBER CF MINES ENCOUNTERED =    .165

    PROB. OF ENCOUNTERING NO MINES    IS    .848
    PROB. OF ENCOUNTERING  1 MINE(S)  IS    .140
    PROB. OF ENCOUNTERING  2 MINE(S)  IS    .012
    PROB. OF ENCOUNTERING  3 MINE(S)  IS    .001
    PROB. OF ENCOUNTERING  4 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING  5 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING  6 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING  7 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING  8 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING  9 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 10 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 11 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 12 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 13 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 14 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 15 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 16 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 17 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 18 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 19 MINE(S)  IS    .000
    PROB. OF ENCOUNTERING 20 MINE(S)  IS    .000
```

316

CDC 6600   CACI SIMSCRIPT II.5 VERSION /4.5-00/ NOS-BE 1   12/24/81 08.43.28.   PA

```
     FUNCTION PLAY(A, B)

       RETURN WITH 3/SQRT.F(PI.C*2)*EXP.F(-1/2*(A-0.5)**2*9)
       END ''DISPLAY FUNCTION
```

INPUT FILE

```
40  40  40
-.5 1.5
1.1
1.8
```

```
LOWER, UPPER BOUNDS ON VEHICLE PLAY =   -.50,   1.50 METERS
      CENTER TO INSIDE TRACK EDGE =  1.10 METERS
      CENTER TO OUTSIDE TRACK EDGE=  1.80 METERS

   EXPECTED NUMBER OF MINES ENCOUNTERED =    .473

   PROB. OF ENCOUNTERING NO MINES    IS   .623
   PROB. OF ENCOUNTERING  1 MINE(S)  IS   .295
   PROB. OF ENCOUNTERING  2 MINE(S)  IS   .070
   PROB. OF ENCOUNTERING  3 MINE(S)  IS   .011
   PROB. OF ENCOUNTERING  4 MINE(S)  IS   .001
   PROB. OF ENCOUNTERING  5 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING  6 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING  7 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING  8 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING  9 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING 10 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING 11 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING 12 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING 13 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING 14 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING 15 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING 16 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING 17 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING 18 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING 19 MINE(S)  IS   .000
   PROB. OF ENCOUNTERING 20 MINE(S)  IS   .000
```